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The Traversella mining site as Piemonte geosite

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Abstract

The Traversella mining area, nearly 60 km North of Torino, was, together with Brosso, a very important mining district for iron exploitation. The Traversella ore deposit was exploited from late Medieval Age up to the middle XX century. It is a typical skarn deposit at the contact between a dioritic body and preexisting metamorphic host rocks, which represents the only exploited skarn-type mineralization in the Alps. The iron ore mineral, exploited from different orebodies, was primarily magnetite. After the beginning of XX century the extraction involved also pyrite and chalcopyrite, used mainly for the production of sulfuric acid. The mine, after some interruptions and re-openings, was officially closed in 1971, due to the high exploitation costs and the competition of the foreign iron ore deposits.

The present research aims to emphasize the extraordinary importance of this mining site both from a scientific and a historical point of view, by also examining the exploitation and ore processing methods and the amount of production during the last three centuries, and highlighting how these activities contributed to the industrial development of the surrounding area and of the whole Piemonte Region. It aims also at illustrating the sociological and environmental impact of mining activities at regional level, highlighting the importance of the site from a geotouristic point of view, through the cultural exploitation of the mining site remains, the development and upgrade of the already existing mining museum, and the organization of geotouristic itineraries.

Key words: iron mine, skarn-type mineralization, minerals association, geotouristic route, industrial archeology, cultural heritage.

1. Introduction

The present paper is the result of a research activity developed within the framework of the multidisciplinary project PROGEOPiemonte, started in 2012, in which nine strategic geothematic areas have been selected to be investigated as representative of the geodiversity of Piemonte Region (Northern Italy) (Ferrero et al. 2012). The dissemination of the knowledge connected to geological history, climate and environmental changes, natural hazards, soil processes and earth resources, not only of the geosites but also of the museum collections, has been and is spread, evidencing the mining and quarrying activities, and by means of science exhibits and nature trails. Among the nine selected geosites, there is the Traversella mining area, object of the present research.

Traversella village lies in Val Chiusella, about 60 km North of Torino (Piemonte Region), and it has been (together with the neighbor site of Brosso) one of the most important mining sites for iron exploitation (Fig. 1): the first traces of mining activities date back to the late Middle Ages, with some evidences from Roman Age. The village (Fig. 2) is characterized by typical buildings (Fig. 3) made of local stones and wood: stones for the roofs (for the typical *lose* – dialect word to indicate flat and squared slabs) and wood for the balconies. The history of the village and of the valley has been highly influenced by the presence of exploitable ore bodies, with a florent wealthy period in XVIII-XIX centuries, when the iron mines were more active.

Traversella mine was an important source of livelihood for all the Bersella and Chiusella valleys during XVII and XVIII centuries. Although the work in mine was dangerous and sometimes lethal, it was most of time the greater resource for a small community devoted formerly to farming activities. *“we can imagine of what the mine is, thinking of an enormous heap of incoherent mineral blocks, always ready to collapse. It is mainly in the rainy season that the work in the mine is very dangerous; water infiltrates everywhere, expands and carries around the sand that glue the blocks, and stretch the mineral to the bottom. Small and big collapses are then very usual”* (from Falquet report, 1829, cited in Berattino 1988).

The presence of a mine caused the growth of a multitude of connected activities that involved different workers of the area: mining transport, pack animals driving, construction and management of the ovens, fabrication of metallic hardware, cutting and shaping of wood for mining infrastructures, paths and roads maintenance, check point surveillance, guest house management and maintenance, restoration and tavern management, and so on.

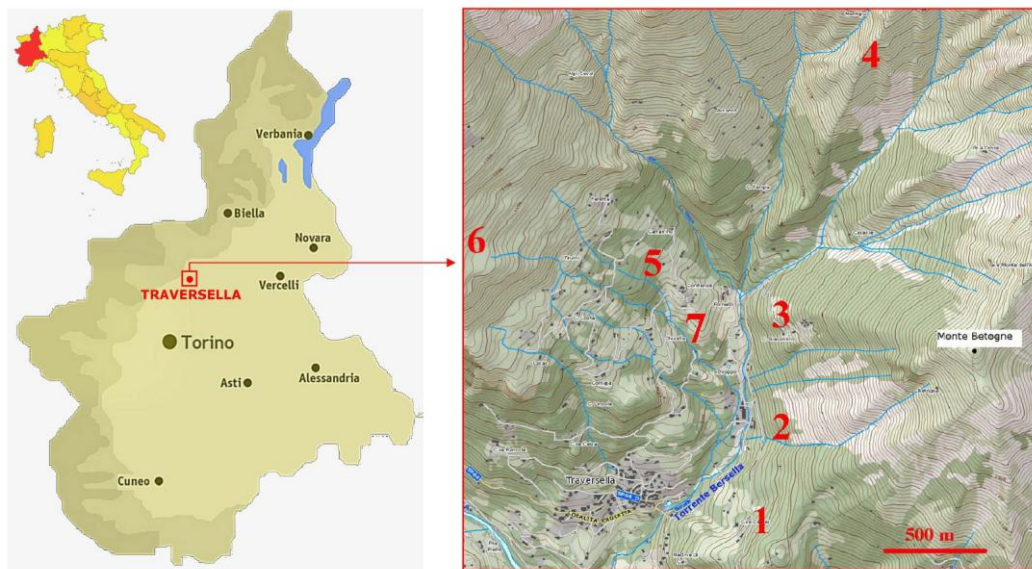


Figure 1. Location of Traversella village. The main extractive areas in the past were: 1. Cevreij; 2. Riondello; 3. Castiglione; 4. Montajù-Pian del Gallo; 5. Carrairino; 6. Balma Bianca; 7. Ferriere



Figure 2. View of Traversella village



Figure 3. Typical building made of local stones

The present research aims to emphasize the extraordinary importance of Traversella mining site both from a scientific and a historical point of view, examining the exploitation and ore processing methods and the amount of production during the last three centuries, and highlighting how these activities contributed to the industrial development of the surrounding area and of the whole Piemonte Region. The area still presents several signs of mining and dressing activities: underground workings (open under severe restrictions), traces of the dressing plant, offices, miners changing room and canteens, etc. Such signs represent the tangible trace of a remarkable industrial activity, which can be considered as cultural heritage (“industrial archeology”). To enrich such cultural heritage, a museum for minerals and mining tools exposition is still active; to evidence the importance of Traversella mining site, outstanding mineralogical samples coming from Traversella area are displayed in the most famous museums all over the world.

2. Geological background and ore deposit feature

As shown in the inset of Fig. 4, from the geological point of view the Alps are composed of several Domains (Penninic, South-alpine, Austroalpine and Helvetic Domain), each of them is composed of rocks which share a common area of origin before the alpine collision, i.e., before the collision between the northern European (to the north) and the apulian plate (to the south). The Helvetic Domain, for instance, includes rocks belonging to the former European plate, while the South-alpine Domain is composed of rocks belonging to the apulian plate. The Penninic Domain includes rocks related to an ancient oceanic basin of Jurassic Age (the so called Thetys basin) and to its northern continental margin, that were strongly metamorphosed and deformed during the alpine collision. Finally, the Austroalpine Domain represents a portion of the South-alpine Domain that was translated to the north, above the Penninic Domain. Domains are limited by thrust and/or fault planes, which are shown with thick lines in the inset. The most important of them is the Insubric Lineament, composed of a series of faults that mark the contact between Penninic and South-alpine Domains.

A number of intrusions occur broadly aligned along the Insubric Lineament, which represent the main products of the “Periadriatic Magmatism”, a magmatic event of Eocene to Oligocene Age (ca. 43 to 29 million years ago), originating plutons (north-east to south-west in the inset of Fig. 4: Adamello, Bregaglia, Cervo, Miagliano, Traversella), volcanic rocks and dykes. Such event post-dates the main phases of formation of the alpine belt: in fact, the magmatic bodies are not affected by the alpine metamorphism and deformation.

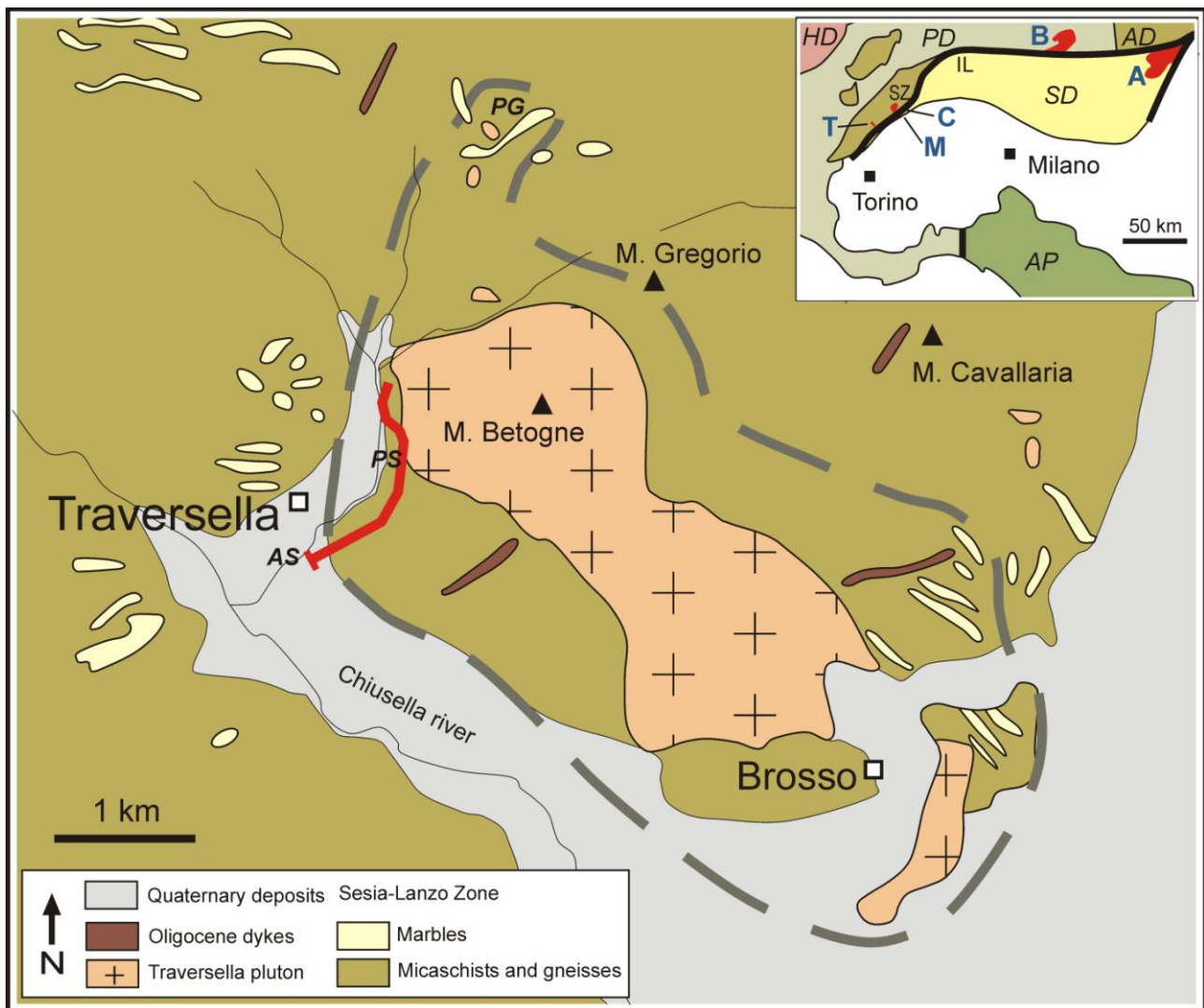


Figure 4. Simplified geological sketch-map of the Traversella area. PG: Pian del Gallo; PS: Pian degli Svedesi; AS: Anglosarda adit (the approximate projection of the main gallery to the surface is also shown). Dashed line: approximate extent of the contact aureole. The map is modified after Müller (1912), Mattiolo et al. (1959) and Zucchetti (1960). The inset shows the main Domains of the Alps: Helvetic (HD), Penninic (PD), South-alpine (SD) and Austroalpine Domain (AD), the latter including the Sesia Lanzo Zone (SZ). Main intrusive bodies related to the Periadriatic Magmatism: Adamello (A), Bregaglia (B), Cervo (C), Miagliano (M), Traversella (T). Thick lines show the main fault systems (IL: Insubric Lineament). AP: Apennine chain.

The Traversella mineralizations are strictly related to the homonymous pluton, an intrusive body of quartz-diorite to monzodiorite composition of Oligocene Age (ca. 30 million years). Compared with other Periadriatic intrusions, the Traversella pluton is relatively small: ca. one fifth of the Cervo pluton and less than one hundredth of the huge Adamello intrusion. The Traversella pluton intruded, like the Cervo pluton, the Sesia Lanzo Zone, a tectonic unit belonging to the Austroalpine Domain mainly composed of micaschist and gneiss, with minor metabasite bodies (Fig. 4). However, the Traversella area shows two important differences compared to the Cervo area: the occurrence, within the host micaschist and gneiss, of layers of carbonatic rocks (mainly dolomitic marble); and, of course, the presence of the ore deposits. Also the Brosso ore deposits, at the south-eastern border of the same pluton, are related to the intrusion, though displaying rather different features. However, this paper only deals with the Traversella deposits, which have been the focus of new studies in the last years.

2.1 Traversella: an insight into a mineralized skarn system

In the geological literature the Traversella ore deposits are classified as “skarn deposits”: the term “skarn” (from an old Swedish mining term: Törnebohm 1875) is adopted, all over the world, to indicate analogous deposits that today still represent an important source of metals like W, Fe, Au, Cu, Zn, Mo, Sn and, locally, industrial minerals (Meinert et al. 2005). Skarn is a peculiar rock whose formation is related to metasomatic processes connected with the interaction between hot fluids (generally, though not always) exsolved from an intrusive body and pre-existent host rocks. Such an interaction causes strongly changes in the chemical composition of the host rock, generally resulting in the formation of

garnet, pyroxene and possibly many other minerals. Skarns are not common at all, and mineralized skarns (i.e., skarn deposits) are a minority: particularly, Traversella represents the only mineralized skarn deposit of the Alps. Magmatic related skarns are complex systems composed of several components: a magmatic body, country rocks affected by contact metamorphism and different types of skarns and related mineralizations. Other features, like hydrothermal veins and breccias, may also occur. All these components are present in the Traversella skarn system, and can be seen both in outcrops on the surface and underground: they are briefly described below.

a) Magmatic body

The magmatic body, which can be considered as both the source of the metasomatizing fluids and the “thermal engine” of the system, is a medium- to fine-grained plutonic rock ranging in composition from quartz-diorite to monzodiorite. Its best exposures occur within old and active quarries close to Traversella and Vico Canavese villages (Figs. 5a, b), or along the Anglosarda tunnel (AS in Fig. 4).

b) Country rocks affected by contact metamorphism

The host rocks of the Traversella intrusion are represented by metamorphic rocks like micaschists and gneisses, with minor bodies of metabasites and dolomitic marbles. Approaching the intrusion, all these rocks are affected by a strong contact metamorphism, whose main macroscopic effect is the recrystallization of the marbles and the change in colour of the micaschists, which become black due to the development of abundant biotite replacing phengite; close to the contact biotite also overgrows garnet, which changes from red to black. These transformations can be seen, on the surface, in the Pian del Gallo mining area; the changes in the micaschists approaching the pluton can be observed at best along the Anglosarda tunnel (Figs. 5c, d).

c) Skarns and mineralizations

The most typical feature of the skarn systems worldwide is the development of several types of “skarn rocks” close to the plutonic body. Like in other skarn systems, at Traversella two main types of skarn occur.

A first type, often described as *prograde skarn* in the literature, is given by the spectacular development of granoblastic rocks mostly composed of diopside and garnet (Fig. 5e). These rocks completely replace the pre-existing rock: scanty elongated garnet domains grown on the former metamorphic foliation are often the only structural relic of the primary country rock. The prograde skarns occur at the immediate contact with the dioritic rocks and formed at high temperature, as a product of metasomatic reaction between magmatic fluids and dolomitic marbles, with addition of silica (and other elements) that allowed the formation of diopside, garnet and often also forsterite. Outcrops of prograde skarns can be observed in the Pian del Gallo and Pian degli Svedesi mining areas, and along the Anglosarda tunnel (Fig. 4).

The magnetite ore of the Traversella mine occur broadly as N-S aligned bodies, subparallel to the intrusive contact. Along the Anglosarda tunnel their relationship with the host rocks is well exposed: they are generally located at the outer limit of the main prograde skarn bodies, between them and the cornubianitic country rock (micaschist and dolomitic marble). Although the latter ones may display some magnetite enrichments (common in the marbles, for instance), the outer limit of the orebodies is sharp. As it can be observed with a hand lens (and much better under the microscope), magnetite, relatively coarse-grained, is mostly associated with forsterite and/or diopside (and their retrogression products: see below) (Figs. 5e, f): this suggests that the magnetite orebodies themselves are an iron-rich variety of the prograde skarn.

The second type of skarn, also called *retrograde skarn*, is represented by the development of lower temperature minerals which overgrow the prograde skarn assemblage. The retrograde skarn is related to the circulation of fluids causing hydration of the previous skarn assemblage, with formation of a number of different mineral phases: the petrographic observations show, in fact, that such a retrograde stage is polyphasic, as developed over a range of progressively decreasing temperatures (Marcelli 2016). Moreover, related minerals may occur both as replacement products of the previous assemblages and along crosscutting veins and fractures. Typical minerals related to retrograde skarn include talc, amphiboles (mainly tremolite and actinolite), carbonates and chlorite; scheelite probably mostly formed during this stage. Sulphides, which are rare in the prograde skarns, are common, mainly as pyrrhotite, pyrite, chalcopyrite and arsenopyrite. At Traversella, retrograde skarns are common: they occur, for example, along the Anglosarda tunnel, close to the Massa Bertolino orebody, and are widespread along the galleries in the upper levels of the mine (e.g., along the 826 level – Mongenet) (Figs. 5g, h).

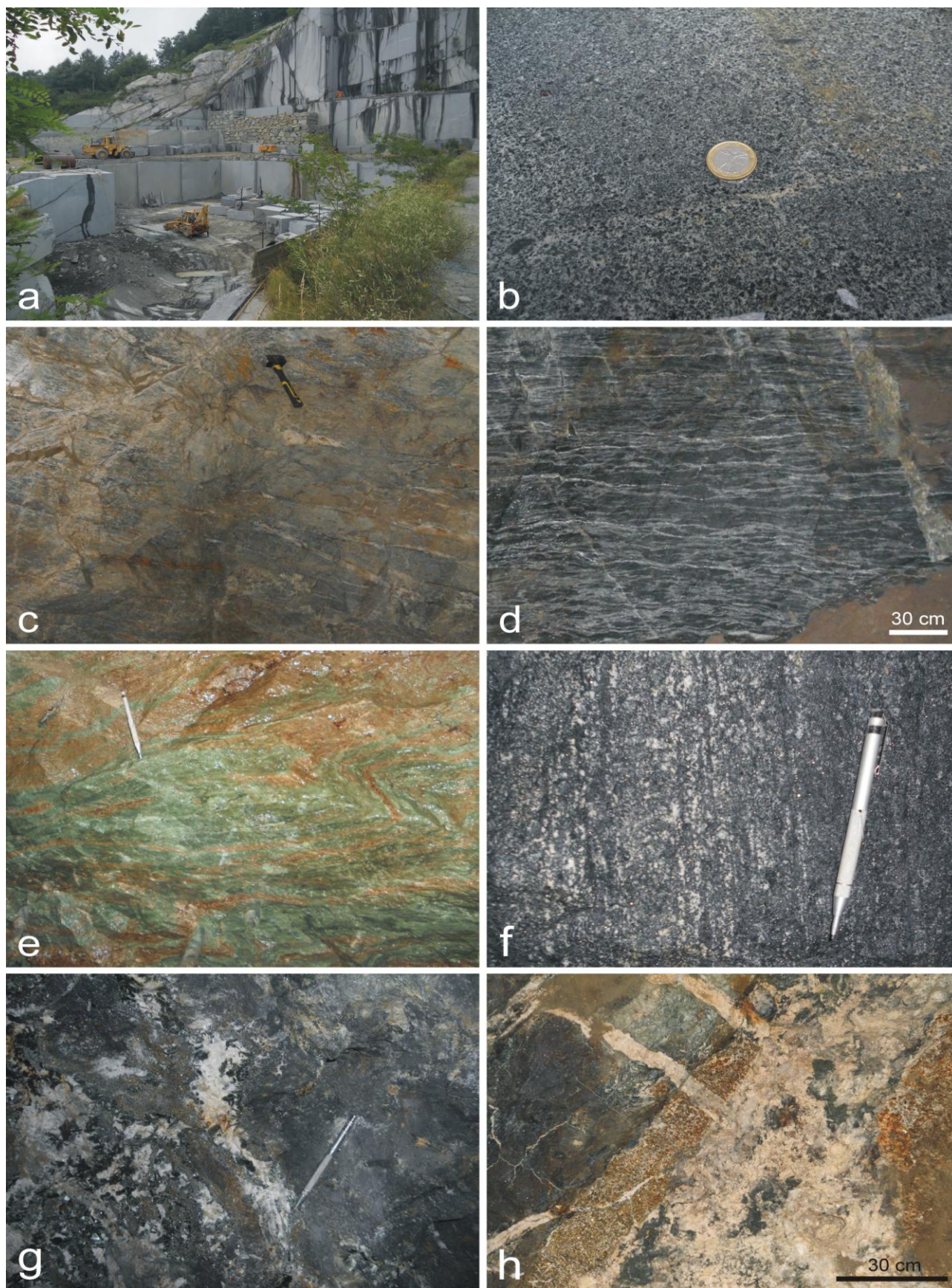


Figure 5. Typical features of the Traversella “skarn system” in the field. a, b: magmatic rocks. a: Vico Canavese quarry of “diorite”, b: typical aspect of the dioritic rocks. c, d: country rocks affected by contact metamorphism approaching the pluton, along the Anglosarda tunnel. c: micaschists at beginning of the tunnel (ca. 1 km from the contact), d: same rocks some tens of meters from the pluton. Close to the intrusion the micaschists become almost completely black do to the growth of biotite. e, f: prograde skarn

and mineralization along the Anglosarda tunnel. e: typical prograde skarn, mostly composed of diopside (green) and garnet (red). The orientation of the monomineralic domains broadly corresponds to the former metamorphic foliation. f: magnetite mineralization from the lowest part of the Massa Bertolino orebody. The rock is mostly composed of magnetite, associated with variable amounts of calcite and partially serpentinized olivine. g, h: retrograde skarns and features related to late hydrothermal circulation. g: massive magnetite (dark grey) is crosscut by irregular-shaped patches of calcite (pure white), coarse-grained chlorite (dark green) and minor sulphides (not clearly visible in the photo). h: the prograde skarn has been completely replaced by amphibole and chlorite (upper left, green massive rock) and is crosscut by veins strongly enriched in sulphides (mostly pyrite and chalcopyrite) which are, in turn, crosscut by carbonate-rich veins. Brecciated portions mainly consisting of carbonate, quartz and amphibole (and/or chlorite) also occur (centre of the photo).

The late circulation of fluids also led to the formation of several types of hydrothermal veins and breccias, whose composition is highly variable: many “collection samples” of minerals like quartz, different types of carbonates, pyrite but also gold, galena and many other phases (see below) are related to this post-skarn circulation along open spaces, which often allowed the crystallization of minerals with great aesthetic interest, particularly at the upper levels of the mine.

3. Mining activity: historical evolution

The abundance of iron ore in the Chiusella Valley, well known all around Europe, is strictly connected to the intense mining activity that probably began in the Roman Age. Some evidences of that have been found in the Chiusella Valley area: indeed, recently, close to the Traversella village, in a so-called “*croso*” (a small exploration tunnel for iron ore), some coins from Roman Age (around 300 BC) have been found. But the clear traces of the mining activities arise to 1487, year indicated in a documental proof of extraction works in the area, within a Claim from the Savoy administration, which sentences that “*inhabitants of Brosso and Traversella must stay in their free and pacific possession of iron ore*”. At the beginning (late Middle Ages) the “mine” was represented by a scattering of small family concessions that were exploited without organization.

Other traces from mining activity in the area are dated 1570, when a lawsuit refers that in Traversella area: “*iron ore is extracted from 10, 20, 30, 40, 50, 60 and more years, and so much time, and there is no memory of living man against this claim...*”.

The various sequences of events, the alternation of war and peace periods, surely impacted mining activity which, at that time, was sporadic and not primary. The extraction was limited to open pit yards where the ore was clearly visible on the surface, and the main activity of local people was based on agro-pastoral activities whereas mining was concentrated in winter and late autumn, when agriculture was less demanding. Probably, starting from XVI century and with the increase of iron demand for civil and military uses, the mining activity increased more and more¹, at first in the area of Brosso, connected in a better way to the surrounding territory, and later in Traversella area. The ground-level boundaries of single properties were uncertain, and the underground work was not planned, and characterized by a frequent tunnel crossing (in this case the two miners should reverse the digging direction). Tunnels were often excavated below other tunnels, so collapses were frequent, and was common to discharge water infiltration in the other tunnels. The valley slope was an anthill, so that fall and runoff were common.

During the XVIII century the mining activity boosted, probably thanks to the discovery by Bernardo Mutta (1716) of the main ore vein in “*Pian del Gallo*” site. The mining activity became very important for the Traversella area, and in 1723 the Savoy resolved to apply a taxation on the amount of mineral produced. In 1753, the tax amount was about 5 *denari* for each *rubbo*² of mineral, but only few years after this tax was reduced to 2 *denari*; in terms of equivalent buying power, a kilogram of bread could have a price of 60 *denari*. In 1840, the taxation was fixed in 0.1 *lira* for each *rubbo*, about 0.50 € converted nowadays for a handful of ore. Although a lot of difficulties remains about the determination of the real quantity of excavated ore (also because of illegal diggers, fraud about weighing, distraction of minerals from the local customs using uncomfortable and mountain-crossing tracks), the income from mineral tax was so high that, in the Traversella area, any other kind of taxation was abrogated, eliminating the fiscal pressure on the local citizens.

¹ The fact that mining activities arose more and more is confirmed by the lawsuit of “Pietro Saudino from Settimo Vittone” (owner of the mines due to an assignment by Duke Emanuele Filiberto of Savoy), lawsuit against a number of illegal workers that digged a numbers of small cavities and tunnels, without any organization or planning, interfering with the activity of the well organized and authorized mine owners.

² The *Rubbo* was an old mass unit used in Savoy, and it is more or less equivalent to 9.2 kg.

The 1732-1884 period is known to be the golden age for Traversella (Berattino 1988, Gruppo Mineralogico Valchiusella et al. 2005): the mining works became the main activity contributing to the economy of the valley, and never after that period iron extraction have achieved this prominence. At the beginning of XIX century the resident population was around one thousand individuals, whereas at the end of the same century the population reached a never surpassed peak of almost two thousand people (nowadays the municipality comprises about 400 individuals) (Fig. 6). At the end of '800 many problems affected the Traversella mine, with the suspension of the extraction activity and reduction of the mined ore. In 1883, the last owner declared only 17000 *rubbi* of production, and the very next year he decided to close the mine. The delay in technological innovation, the occurrence of foreign mines with lower extraction costs and the underdevelopment in the transport net contributed to accelerate the inglorious conclusion of Traversella mining activity.

At the beginning of the XX century the mining site was acquired by the *Società Anonima delle Miniere di Traversella*, and after various handovers, the mines were finally acquired in 1914 by FIAT. In the XX century the exploited mine is a huge net of galleries, wells and caves excavated in the mountain (Fig. 7). The mining activity was interrupted again, but with the arrival of fascism and autarchy, the mine was further exploited and in 1938 a cableway was built for quick delivery of the ore to the nearby railway station of Montalto Dora. With the starting of the WW2, any extraction was suspended. In the immediate postwar period many efforts were put to restart the production, but the poor quality of the ore, the high cost of extraction and the increasing competition with other iron resources around the world, had lead to the definitive closure in 1971 (Gruppo Mineralogico Valchiusella et al. 2005).

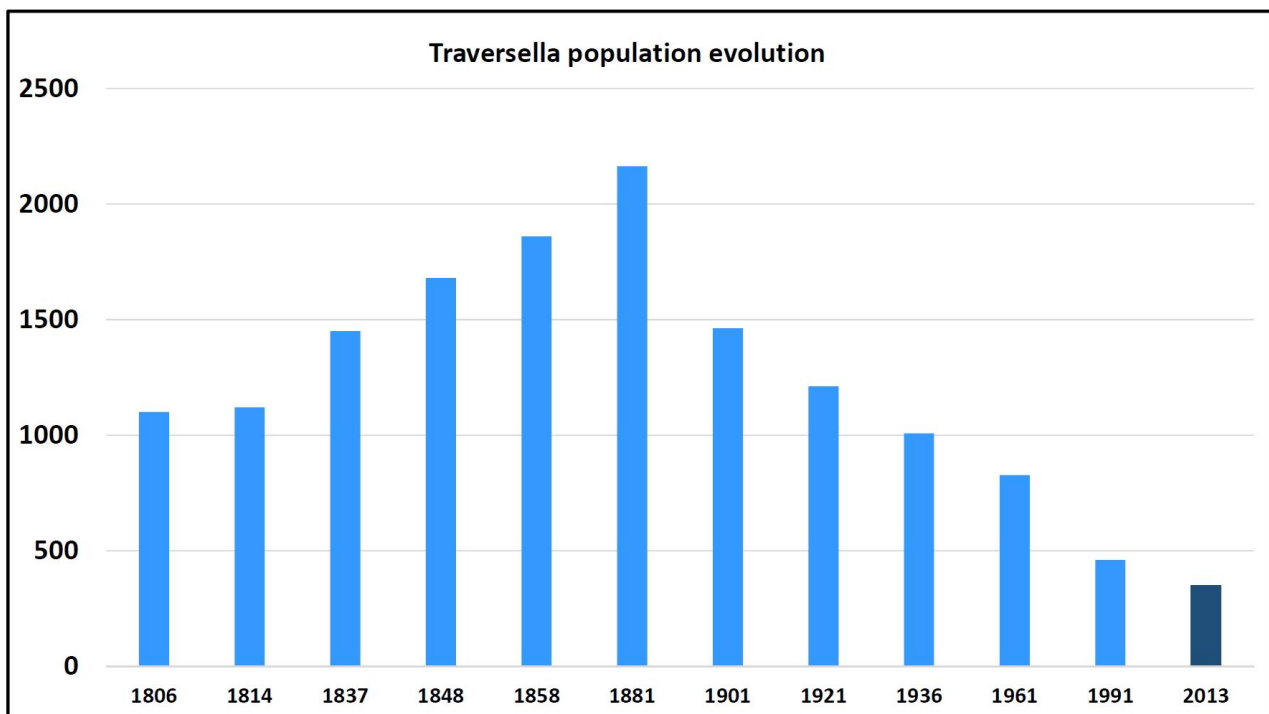


Figure 6. During the period characterized by a very florid mining activity, the population reached the acme. The mines were never declared exhausted, but the competition with abroad mines and the delay in industrial development lead to their inglorious closure. The actual population of Traversella municipality is around 400 individuals.

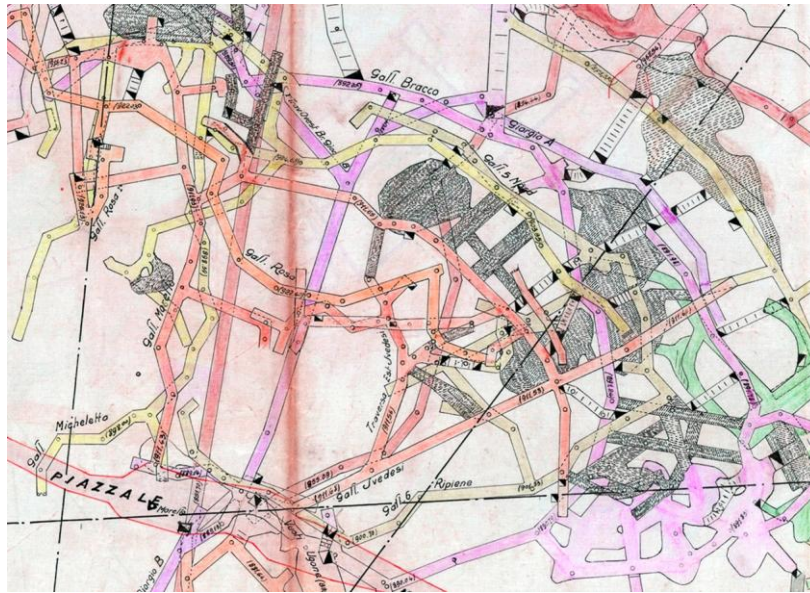


Figure 7. Part of a drawing of the galleries existing in the late '50 (XX century): the exploited mine is a huge net of galleries, wells and caves excavated in the mountain.

We have (due to the tax burden) an exhaustive documentation of the production of the mine area during 1700 and 1800. As an example, in 1745 the production was 100.000 *rubbi*, so the total amount of ore was roughly 920 tons. In 1750 the production rose to 190.000 *rubbi*, and in 1794 an important production of 700.000 *rubbi* was reached. The maximum was obtained in 1829, when the goal of nearly a million of *rubbi* was achieved. Starting from that epoch, a continue and slow decline was observed in the mining area (Fig. 8).

The total amount of iron ore produced in the Traversella complex during the period 1723 – 1884 has been estimated in 342.000 metric ton (114.000 metric ton of Fe, evaluating a yield of about 1/3). The total iron casted from the ore body (evaluating a yield of about 1/3) could be approximately considered equivalent to fourteen-times the iron used to build the Tour Eiffel (Fig. 9).

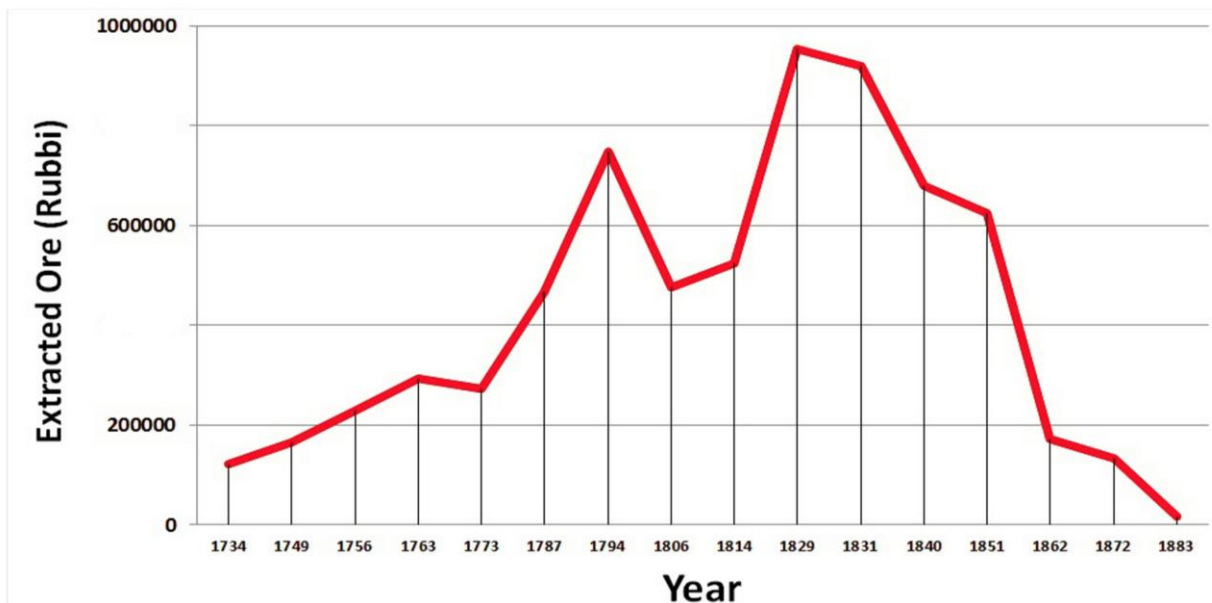


Figure 8. The amount of extracted ore was measured in «rubbi». We owe the abundance of information about the production, in the specific period, to the taxation imposed on the weight of extracted mineral. For fiscal reasons these amounts were registered and, with some exceptions, the registrations logs are preserved. The production is probably underestimated, because many diggers and mine owners tried to hid part of the production to avoid taxations.

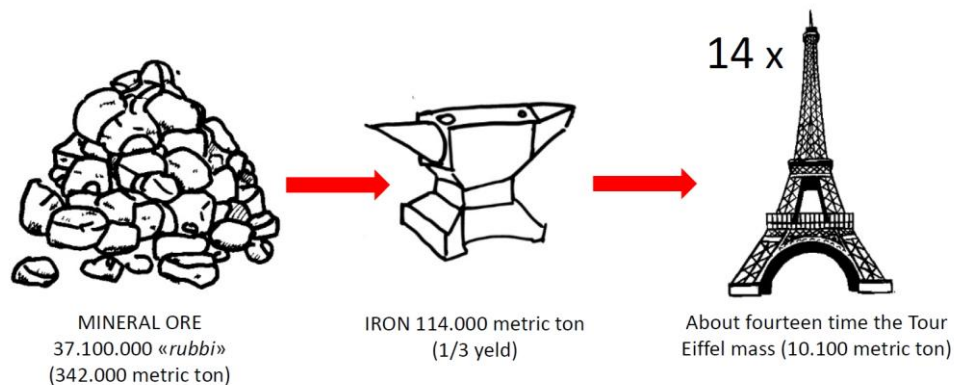


Figure 9. Total amount of iron ore (37 100 000 rubbi, 342.100 metric ton) produced in the Traversella complex during the period 1723 – 1884. The total iron casted from the ore body, (evaluating a yield of about 1/3) could be approximately considered equivalent to fourteen-times the iron used to build the Tour Eiffel.

4. Dressing activities: new technologies applied first at Traversella

Lots of technological innovations, pioneers for the treatment of minerals, have seen their birth at Traversella; these innovations, together with mining activities at large, have marked the territory of Traversella and its relevance at national level. In 1854 Quintino Sella (on behalf of Count *Riccardi di Netro*, later died in 1884) designed and realized a rotating magnetic separator, in order to guarantee more efficient minerals separation (Fig. 10). The magnetic separator was designed to recover from the extractive waste facilities the still present and potentially exploitable copper minerals, difficult to select through common manual sorting. It consisted of a cylinder with 48 fixed magnets, which allowed to attract the magnetic minerals present in the feeding material (grinded and screened before separation). Based on Faraday's studies (1845) about magnetic properties of minerals, Sella designed a machine that used electro-magnets to separate magnetite from the other minerals. In 1855 Quintino Sella obtained the *Privilege* for the mineral dressing, thanks to electromagnetic separator, of copper ores containing magnetite; this *Privilege* (forerunner of current patents) lasted fifteen years (Gilli 2007). Magnetic separators were then installed at Traversella by FIAT company almost a century later (mid XX century). This invention, which has become famous throughout the world, was further refined, changing into magnetic belt separator, using a belt to carry on the minerals in the field of action of an electromagnet. Sorting by magnetic separation is also the basic principle of modern machines designed to separate the recoverable metal components inside other waste (treatment of plastics, glass, rubble, etc.).

When in 1900 the Traversella mines passed to the *Società Anonima delle Miniere di Traversella*, new treatment methods for separating copper minerals from mixed magnetite sulphides were tested. In particular, Froment wanted to test the process invented by Elmore (in 1896), which consisted in separating several minerals thanks to the affinity between sulphides and dense combustible oils. Such test was not completely satisfying, but, on the basis of the results achieved, it was possible to observe that, thanks to the water-repellent behavior of the sulphides (wetted with small amounts of oil), by adding gas to the turbid, it was possible to obtain a foam which acted as a transport vehicle to the surface for the sulphide grains. This process was patented as "froth flotation" (Fig. 10); even if this process still showed some weaknesses, it has marked the Italian and international mining industry. In 1904, due to the bad economic condition of the company, the patent was sold for £ 225 to the Minerals Separations Ltd., which exploited it internationally. The following improvements allowed the passage from "pilot plant" to "industrial plant". This enrichment technique is still valid and employed for the separation of metallic sulphides, talc, feldspar, barite, fluorite, etc.

In the 1930s, mining activities were carried out for the recovery of iron and copper minerals. However, in the same years scheelite, associated to the main ore minerals, was also found in mining and landfill areas. This finding leads to the hypothesis of tungsten recovery using shacking tables present in the treatment plants.

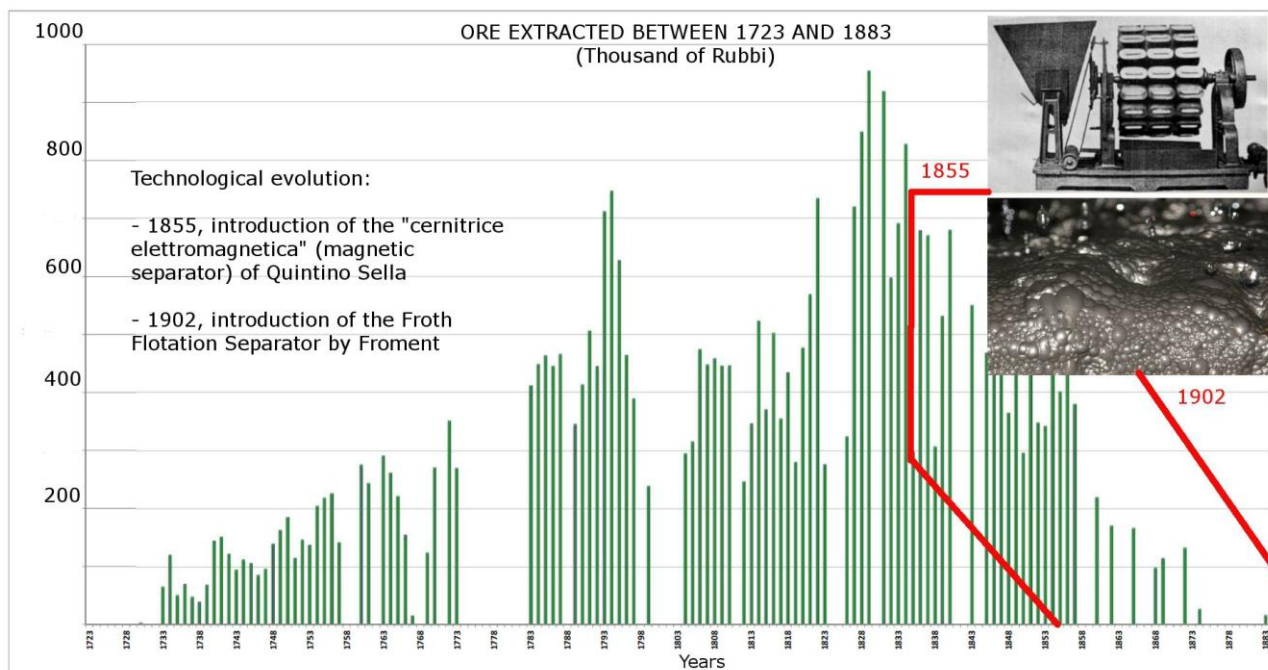


Figure 10. Technology evolution, compared to iron exploitation. Rotating magnetic separator and a froth flotation separator are reported in the picture.

5. The minerals of Traversella

Traversella is a geological heritage of inestimable international scientific value since it is a very important mineralogical site, famous throughout the world for providing, in addition to the minerals of industrial interest, such as iron ore (magnetite and pyrite), tungsten (scheelite) and, to a lesser extent, copper, also a lot of “collection samples” of great aesthetic interest, as carbonates and silicates. Indeed, the exceptional conditions of genetic variability, created by the intrusion of the monzodiorite, generated in Traversella one of the highest concentrations in the world of mineral species in a few square kilometers. *Mineralized skarns* have provided to mineral collectors beautiful crystals among which: magnetite, in large rhombododecahedral crystals with the typical striated faces; colourless quartz, or green (prase) or purple (amethyst); dolomite, in colourless rhombohedral crystals, partially encrusted by black lamellar hematite; calcite, with prismatic or scalenohedral habit; “mesitine”, an iron-rich magnesite, in lenticular crystals; scheelite, in bipyramidal crystals in a fine-grained talc matrix; “fassaite”, a variety of pyroxene. The particularly elegant association of large crystal of quartz, dolomite, calcite and “mesitine” is well represented all over the most important and prestigious museums in the world. Indeed, several mineral samples extracted in Traversella enrich today the collections of Italian, European (Torino, Milano, Roma, Napoli, Bologna, Padova, London, Paris, Prague, St. Petersburg, Stockholm, Vienna, etc.), and North American museums (Piccoli et al. 2007).

In the “Museum of Minerals and Equipment of Traversella Mine”, sited in the original dressing plant (crushing area), in addition to the mine equipment and to the original instruments, nearly 800 samples of various minerals are exposed to the public.

5.1 The common mineralogical species

The minerals of Traversella mine were mentioned in the first mineralogical manuals and publications from the 1800s. In the Catalogue of Barelli (1835), 18 mineral species are mentioned, while Strüver (1869) reported 36 and Torti (1973) already 70 minerals in the 1970s (Gallo 2007, Costa and Gallo 2010). Currently, 98 species are listed as valid minerals and from 2016 Traversella is Type Locality (TL) of a dark greenish amphibole, the ferro-ferri-hornblende (Oberti et al. 2016). The minerals present in Traversella can be catalogued in groups, summarized in following:

5.1.1 SULPHIDES

Galena. Galena, the cubic lead sulfide PbS, is a relatively common mineral in Traversella; it is mostly in massive form, associated with other sulphides, and quite rarely in well-formed crystals in the cavity of carbonate rocks, often with quartz, siderite and dolomite. The size of the crystals varies from a few millimeters to 5 cm; exceptionally reaches 10 cm. The crystals have cubic or octahedral, rarely dodecahedral habit and show a perfect cleavage. The colour is gray-lead with very bright metallic lustre, but the surface is often altered. In some areas of the mine galena undergoes an

intense process of oxidation, generating a series of secondary alteration minerals: cerussite, anglesite, wulfenite, stolzite.

Pyrite. Pyrite, the cubic iron sulfide FeS_2 , is very common in Traversella and is present in almost all areas of the mine, associated with other sulfides such as arsenopyrite, pyrrhotite, chalcopyrite. Samples of exceptional size and beauty, particularly interesting for morphological variability, were studied by Strüver (1869) and made famous throughout the scientific community. Pyrite shows numerous and complex crystalline forms with crystals sometimes quite large (some exceed 10 cm), with faces usually striated. The common habit is cubic or pyritohedral, rarely octahedral and dodecahedral. The crystals are sometimes twinned (*iron cross*). Colour is typically yellow-brass, with bright metallic lustre and often iridescent tarnish.

5.1.2 OXIDES

Hematite. The iron trivalent oxide, hematite (trigonal, Fe_2O_3), is found in the marbles, at contact with the mineralized deposits, in geodes with quartz and carbonates. Hematite often results in very elegant associations, thin tabular crystals, blacks, about 4-5 cm sized, associated with crystals of garnet and “fassaite” or in *rose-shaped* aggregates (*iron roses*) on quartz and dolomite. Basal faces often show triangular markings. The colour of hematite is reddish-brown to black, but in earthy masses it is red. The lustre is splendid metallic, often iridescent.

Magnetite. Magnetite (Fig. 11), the cubic iron oxide Fe_3O_4 , is the most widespread and abundant mineral in Traversella mines, occurring virtually everywhere in fine-grained massive form. It was the main subject of the past mining activities for industrial production. In rare samples found in geodes, crystals are well developed and show variable sizes, from a few millimeters to several centimeters. Significant samples of octahedral crystals of really exceptional size, perfectly shaped, brilliant, with a beautiful black ebony colour, are exhibited in the most important museums of the world. The crystals occur with dodecahedral or octahedral habit. The faces are often deeply striated and sometimes partially covered by microcrystalline talc. The colour is dull black, with metallic lustre and sometimes bluish iridescence.

Quartz. Quartz, the trigonal silicon dioxide SiO_2 , is very common in Traversella both as a constituent of the rocks, and in crystals, with a large variety of shapes and colours. At Traversella prismatic pointed crystals are generally very small, not more than 5-6 cm, rarely exceeding 10 cm. Tiny crystals, white or colourless, very splendid, are frequently scattered all over the small cavity walls or on other minerals. It is generally transparent, with bright glassy lustre. Amethyst of Traversella (Fig. 12) is one of the most beautiful varieties of quartz amethyst known in the world and particularly sought-after by collectors, for the exceptional size of the crystals (more than 30 cm) and the deep purple colour.

5.1.3 CARBONATES

Calcite. Calcite, the trigonal calcium carbonate CaCO_3 , is very frequent in almost all areas of Traversella mine, in geodes and cavities also of considerable size, often associated to other minerals (marcasite, pyrite, quartz, carbonates). In some areas it was found in transparent scalenohedral crystals associated with hornblende, chrysotile, clinocllore. The splendid crystals of calcite found in Traversella are famous all over the world. At Traversella it is not uncommon to observe samples reaching 8-16 cm. The crystals show very complex habit, with a great variety of forms (prisms, rhombohedra and scalenohedra). Exceptionally elegant twins are very frequent. The crystals are usually colourless, transparent or translucent, but may assume different colour shades. The lustre varies from glassy to pearly.

Dolomite. Dolomite, the trigonal double carbonate of calcium and magnesium $\text{CaMg}(\text{CO}_3)_2$, has made the Traversella mine famous worldwide for the beauty and the size of its crystals. When the mine was active, crystals of more than 20 cm were found. Dolomite occurs mainly at the contact between carbonate rocks and metalliferous masses, in geodes associated with quartz, carbonates and other minerals (magnetite, hematite, sphalerite, pyrite, marcasite, galena, chlorite, scheelite). At Traversella dolomite occurs as rhombohedral crystals with sharp edges or in curved faces aggregates (*saddle-shape*). The crystals are white, with light shades of yellow, but colourless, or brown or pink samples, with pearly lustre, are not rare. Varieties containing iron often have a dark brown alteration.

Magnesite var. “mesitine”. “Mesitine”, the iron-rich trigonal magnesium carbonate $(\text{Mg,Fe})\text{CO}_3$, is one of the most characteristic minerals of Traversella. The species occurs, associated with quartz, carbonates and sometimes pyrite, in areas separating the various ore deposits. “Mesitine” was described by Breithaupt (1828) as a new species with Type Locality just at Traversella. Afterwards it was discredited and considered a ferroan magnesite (Gallo 2007). In Traversella “mesitine” occurs as lenticular, extremely flattened, partly iridescent rhombohedra. The size is from a few millimeters to 5-6 cm. The crystals are white, beige or yellow-amber, transparent or translucent, with vitreous pearly lustre; dark brown colour when altered.

5.1.4 TUNGSTATES

Scheelite. The calcium tungstate industrially extracted for the production of tungsten, scheelite (tetragonal, CaWO_4) occurs with variable abundance in all levels of the mine. The old euhedral crystals, often exceeding 10 cm in size, preserved in several museums and private collections, came from the highest levels of the mine, now inaccessible due to collapses and fills. The classic form of scheelite is the pseudo-octahedral bipyramid, with sharp edges. The large

crystals are frequently incorporated into talc, chlorite or calcite, while smaller crystals can be found typically in spathic calcite, associated with magnetite, chlorite, pyrrhotite and chalcopryrite. The crystals are usually yellowish or orange-yellow more or less intense. Scheelite may be translucent or transparent with adamantine to vitreous lustre.

5.1.5 SILICATES

Andradite garnet. In Traversella mine, the cubic garnet andradite $\text{Ca}_3\text{Fe}_2[\text{SiO}_4]_3$ is quite common in crystals also of considerable size. It is found in the external or shallow areas of the mine, in skarns, associated with spathic calcite, amphibole, epidote. Andradite is quite rare in euhedral dodecahedra, with adamantine lustre. The crystals can reach 5-6 cm in length. The colour ranges from brick red to light red, sometimes reddish brown and black.

Epidote. Epidote (monoclinic, $\text{Ca}_2(\text{Fe},\text{Al})_3[\text{SiO}_4][\text{Si}_2\text{O}_7]\text{O}(\text{OH})$) occurs in beautiful crystals in skarns, associated with pyroxene, garnet, amphibole and rarely apatite and green quartz. It is also found in small crystals with quartz and chlorite. The epidote is found in translucent euhedral centimetric crystals, with columnar habit, densely striated, with intense dark green colour and vivid lustre.

Augite var. “fassaite”. “Fassaite”, the aluminum-rich variety of augite clinopyroxene, is found in well-formed crystals in skarns, associated with epidote and garnet. The general formula is $(\text{Ca},\text{Na})(\text{Mg},\text{Fe},\text{Al})[(\text{Al},\text{Si})_2\text{O}_6]$. Habit is stubby prismatic, with an octagonal or square base; sometimes columnar- elongated. Crystals exhibit numerous faces and can reach 3 cm. The crystals are sometimes very shining, dark green or brownish green. Lustre is resinous, pearly on cleavage surfaces.

Diopside var. “traversellite”. Diopside is the main constituent of the pyroxene, garnet and epidote-skarns. “Traversellite” was the old name given to a variety of aluminum rich-diopside, partially altered in amphibole. Diopside is a monoclinic pyroxene of formula $\text{CaMg}[\text{Si}_2\text{O}_6]$. “Traversellite” occurs as green prismatic crystals with square or octagonal section, often in fibrous aggregates lighter in colour. The elongated prismatic crystals, completely replaced by an amphibole felt, can reach a few centimeters in length. The crystals are transparent or translucent, with vitreous lustre, pearly on cleavage surfaces.

Ferro-ferri-hornblende. Ferro-ferri-hornblende is a new member of the amphibole supergroup, with Traversella as Type Locality (TL). The holotype specimen is from the historical collection of L. De Magistris (Oberti et al. 2016) and comes from *retrograde skarns*. The sample was firstly named “speziaite” by Colomba (1914) to honor Giorgio Spezia (1842-1911), professor of Mineralogy at the University of Torino, who in 1905 was the first to develop a method for the hydrothermal synthesis of quartz. “Speziaite” (Fig. 13) was then discredited and redefined as “hornblende”. The formula of monoclinic ferro-ferri-hornblende is $\text{Ca}_2(\text{Fe}^{2+}_4\text{Fe}^{3+})[\text{AlSi}_7\text{O}_{22}](\text{OH})_2$ (Hawthorne et al. 2012). The type material consists of ferro-ferri-hornblende acicular crystals, dark greenish or blackish in colour, embedded in a matrix of fibrous tremolite with minor quartz and calcite.

Clinochlore (chlorite group). Clinochlore $(\text{Mg},\text{Fe})_6(\text{Al},\text{Si})_4\text{O}_{10}(\text{OH})_8$ (Fig. 14) is found in metalliferous skarns, associated with magnetite, chalcopryrite, pyrrhotite, talc and scheelite. It occurs also at contact with *hornfels*. Rare pseudo-hexagonal crystals reaching 5-6 cm are found in geodes associated with “mesitine”, more frequent smaller crystals occur in talc aggregates. The thin plates are translucent with a pearly lustre and show a colour variation in shades of dark green and blue.



Figure 11. **Magnetite.** Two dodecahedral crystals, described by Borson already in 1830 and exceeding 12 cm of side, now preserved at the Regional Museum of Natural Sciences of Torino (catalog number MU2939).



*Figure 12. **Amethyst**. An example of amethyst crystal from Traversella. This quartz variety was found already by Pelloux in 1908, and then rediscovered in 1959 in a large cavity during the excavation in the 3th Ferriere Mass (Gallo 2007), from which this sample comes (Regional Museum of Natural Science, Torino, catalog number M6457).*



*Figure 13. "**Speziaite**". Sample of ferro-ferri-hornblende, described by Colomba in 1914 and dedicated to Ing. Giorgio Spezia as "speziaite". The mineral was later discredited, and was redefined by Oberti et al. (2016). The sample, six-centimeter-long, belong to the collection of the Regional Museum of Natural Science, Torino, catalog number MU15285.*



Figure 14. Clinochlore with chalcopyrite. The clinochlore crystals reach 55 mm of edge. The sample is preserved at the Regional Museum of Natural Sciences of Torino (catalog number M6548).

5.2 The museum of Minerals and Equipment of Traversella Mine

The Museum of Minerals and Equipment of Traversella Mine was built, in 2007, due to the effort of a bunch of mineral collector and passionate (the Gruppo Mineralogico Valchiusella, GMV) with the help of the Traversella Municipality. It exhibits a mineral collection of great scientific interest and a very attractive section devoted to ancient tools and machinery (Fig. 15) (Gruppo Mineralogico Valchiusella et al. 2005).

In the Museum explanatory panels describe the geological origin of the ore deposits and the minerals present in the nearby quarries of diorite (brookite, chabazite, chalcopyrite, prehnite, malachite, stibnite, titanite and quartz). The main room at the ground floor (dedicated to Rodolfo Maffei, founder of GMV and main initiator of the Museum) displays some geological maps of the area, multimedia tools and a collection with classic minerals (quartz, dolomite, calcite, pyrite), industrial minerals (magnetite, scheelite, chalcopyrite) and the rarest minerals (gold, sphalerite, apophyllite, prehnite, amethyst) so far discovered in the mines of Traversella. The main room at the top floor exhibits the mineralogical collection, consisting of over 300 samples of high aesthetic value, remarkable both for their beauty and for uniqueness (Fig. 16). The last room of the Museum (Fig. 17) collects the typical and historical equipments and tools employed in the mines, some bequeathed by the old miners and many recovered inside the tunnels and in the adjoining buildings.

The mineralogical collections of the Museum are in continuous growth thanks to the activity of the GMV members that still operate inside the mines, trying to keep in good condition the galleries and continuing to carry out scientific research, founding interesting mineral samples and new and rare species or assemblages (as cobaltite, erythrite, bismuthinite, silver and tochilinite).

The aim of the Museum is to raise amongst visitors awareness about the geological resources of Traversella, and to promote and disseminate knowledge of the minerals discovered in the area. The Museum offers to the public the opportunity to learn about the Traversella minerals and mines, and at the same time, contributes to their preservation.



Figure 15. Two old suspended carts used for the transportation of ore from the mine to the crushing and milling area, now at the main entrance of the Museum of Traversella.



Figure 16. The main room at the top floor exhibits the great collection of minerals coming from the Traversella mine and surrounding areas, with didactical panels at the walls and more than 800 samples. At the ceiling are still visible the leftovers of two dropping funnels that driven the ore to the crushing apparatus previously hosted in that space.



Figure 17. A room at the top floor, previously hosting the electrical apparatus still partly preserved, exhibits a collection of tools and objects used in the mining activity like hammer, lamp, drills, wooden boxes, coating and so on.

6. Geocultural exploitation

As introduced, Traversella mine has influenced the culture and industrial development of an entire area over the centuries. Visiting Traversella mining sites, the public is fascinated by the immeasurable twist of nature and anthropic activities, so strongly linked to the mining development of the area. In the previous chapters the importance of the geology and mineralogy, together with the importance of mining and dressing activities, have been presented. All these natural and anthropic features of the area, let us to think about Traversella mine as a geoheritage to enhance. Following we suggest some activities which can boost the touristic vocation of the area.

1. Exploration of the mine: it can take place at different difficulties levels:

- Basic level, for not trained tourists, families, etc. the path is carried out only in the most easily accessible areas, such as the Anglosarda yard - Fig. 18, the tunnel which leads to the main elevator, the traces and the buildings interested by mining activities (the entrances of the old tunnels – Fig. 19, the explosives building, the dressing plant, etc.);
- "Expert" level, for trained university students - geologists and engineers, researchers, etc. in this case the route could contemplate selected parts of the Anglosarda yard, but also the visit to the oldest underground yards (galleries excavated in '700-'800), following safely - old winzes – Fig. 20, going to observe the original wood hopper – Fig. 21, the wells and the old mining sites. This visit would include not only the discovering of the mining context, but also the chance to understand and "touch" the most interesting geological and metallogenic aspects (contacts between different *facies*, several types of skarns, the "iron gate", etc.). These routes are partially already used, but should be secured, consolidating the access paths, providing the right protection equipments, etc.;
- Advanced level, for speleologists, climbers, well-trained aficionados, etc. in this case guided tours of the not directly accessible areas can be organized, passing through and climbing wells and tunnels. Something similar to a trip for "mineral exploration", using picks and hammer to exploit beautiful minerals still present in the mine.



Figure 18. Exploration of the mine: Anglosarda tunnel.



Figure 19. Entrance of an old tunnel (Galleria Bracco Giorgio D)



Figure 20. Old winzes.



Figure 21. An original wood hopper, still presenting the original exploited mineral

2 Accessibility and visits to the old dressing facilities (Fig. 22): these activities should be carried out for museum and educational purposes (training activities using dressing equipments, supplied by guidebook explaining the main principles applied in dressing activities, e.g. grinding, magnetic separation, flotation, etc.).

3. Realization of an updated archive, including historical documents and scanned images, original maps and new 3D virtual maps. These documents have to bear witness of the anthropic activities over the centuries, providing useful information for the next generations of researchers.

4. Implementation of the museum: a valuable collection of minerals and mine equipments is already available to the public. This part could be improved, by adding tools and machineries present along the route of the mine, or inviting people to go and have a look to the traces of mining activities still present in the territory (Fig. 23).



Figure 22. Dressing plant, now abandoned and partially used for the Museum of Minerals and Equipment of Traversella Mine



Figure 23. Traces of mining archeology

All these activities could be properly supported by the local community and the Piemonte Region. As well as in other Italian realities (the Prali mine museum, the Geoparks of the Val di Cornia in Tuscany, the historical and environmental Geominerary park of Sardinia, the Geopark of Floristella mine in Sicily, the Monteneve South Tyrolean mine, etc.) or abroad (the Carrières de Lumières in Le Baux in France, the Bochum mining museum in Germany, the English Carboniferous District, etc.), the implementation of touristic mining routes could find economic development. The mine can become, one more time, the core of the livelihood of the area: this time not connected to exploitation but to geotouristic application (a re-birth of the mine). However, this development has not to be linked only to economic interest, or it would die before its birth; it must be intended as the will of an entire community to keep its history, culture and tradition alive, and to share all this knowledge with other citizens (expert and tourists).

7. Conclusion

Traversella area represents an *unicum* for the ore deposit features and mineralogy, studied by internationally renowned researchers. But the area also presents several signs of mining and dressing activities, which are the tangible traces of a remarkable industrial activity, to be considered as cultural heritage (industrial archeology). To enrich such cultural heritage, a museum for minerals and mining tools exposition is still active. Furthermore, to evidence the importance of Traversella mining site, outstanding mineralogical samples coming from Traversella area are displayed in the most famous museums all over the world.

It is not by chance that the invention of two fundamental mineral dressing processes, such as magnetic separation and foam flotation, have seen their birth in Traversella mining context. When an area is alive and the associated anthropic activities are booming, new discoveries can easily be reached: the will to exploit what nature makes available to man in a profitable way leads to the design of technologies that are exported worldwide. Traversella is the cradle of those innovations.

The structure of the mine represents a fragment of modern and contemporary history and shows how the society developed over the years: ancient mining areas characterized by narrow caves and tunnels, in opposition to the more recent extractive areas, characterized by regular and organized structures. The innovations that characterized the history of the mine are not only connected to technology innovation, but also, and above all, to the planning and design of the mining activity itself.

Existing installations and galleries are precious traces of the history of a valley and of the whole community: they represent the record of mining industry, unfortunately unfamiliar in the last few decades. The term Mine itself is often used with a negative meaning, but people often do not consider that without a programmed and sustainable "raw materials" supply, society cannot develop. In this context, the geological and mining wealth that characterizes the Traversella and Brosso mining basin is something to be preserved and enhanced, keeping alive the memory of the "past activities", disseminating mining knowledge and culture. Raw materials supply is one of the pillars of EU policies and it is fundamental to boost scientific knowledge on past (and present) mining industry, even in the cases of cultural exploitations.

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